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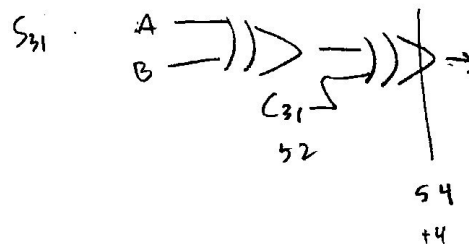
Your task is to find the maximal delay of this design – i.e. determine the delays of S_{0-31} and C_{32} – the maximal delay of these outputs will be the maximal delay of the design. Fill in the values in the table on the following page to receive full credit (and to help with possible partial credit).

Output	Delay	
G0	2T	(2 points)
P0	2T	(2 points)
Gα	12T	(2 points)
Pα	7T	(2 points)
C12	20T	(2 points)
C15	30T	(2 points)
C16	24T	(2 points)
S15	32T	(2 points)
C20	16T	(2 points)
S19	14T	(2 points)
C24	30T	(2 points)
C31	54T	(2 points)
C32 (after mux)	62T	(2 points)
S31 (after mux)	60T	(2 points)

Find the maximum delay **in terms of T** of the 32-bit adder – take the maximum of all output bits – including the sum bits (S_0-S_{31}) and the final carry out (C_{32}). Show your work clearly in the table above. The two figures on the following pages are taken from the class notes, if you need to refer to them.

Maximal Delay: 62T (2 points)

$C_{24} =$



Assume for the rest of this problem that all logic gates have the following delays:

Fan In	Delay
1	T
2	2T
3	3T
4	5T
5	7T
6	10T
7 or more	2T x fan-in

$$14T = 23 + 7 = 30$$

So a 2-input AND gate would have delay 2T and a 4-input OR gate would have delay 5T.

For simplicity, assume that mux's have delay 4T regardless of fan-in.

We will create a 32-bit adder out of some building blocks we've covered in class. We will use the 4-bit CLA that we covered in class as one basic building block of this design. And we will use it (as we did in class) to make 16-bit hierarchical CLAs (HCLA) which will be our other building block. But instead of connecting these in series to make a 32-bit adder, we will use carry select to speed up the 32-bit adder. The design will look as follows (be sure to note where we are using CLAs and where we are using HCLAs):

$$C_{24} = G_{23} + G_{22}P_{23} + G_{21}P_{22}P_{23} + G_{20}P_{22}P_{23}P_{24} + C_{20}P_{22}P_{23}P_{24}P_{25}$$

$\underbrace{23T + 7T = 30T}$
 $\underbrace{44T + 5 = 49T}$
 $\underbrace{23T}$

$$C_{31} = G_{30} + G_{29}P_{30} + G_{28}P_{30}P_{29} + C_{28}P_{30}P_{29}P_{28}$$

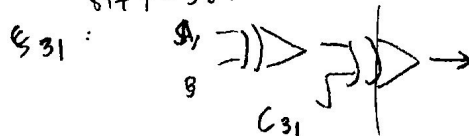
$\underbrace{44T}$
 $\underbrace{49T + 5 = 54T}$

$$C_{28} = G_{27} + G_{26}P_{27} + G_{25}P_{27}P_{26} + G_{24}P_{27}P_{26}P_{25} + C_{24}P_{27}P_{26}P_{25}P_{24}$$

$\underbrace{44T = 37 + 7 = 44}$
 $\underbrace{30T}$

$$C_{32} = G_{31} + G_{30}P_{31} + G_{29}P_{31}P_{30} + G_{28}P_{31}P_{30}P_{29} + C_{28}P_{31}P_{30}P_{29}P_{28}$$

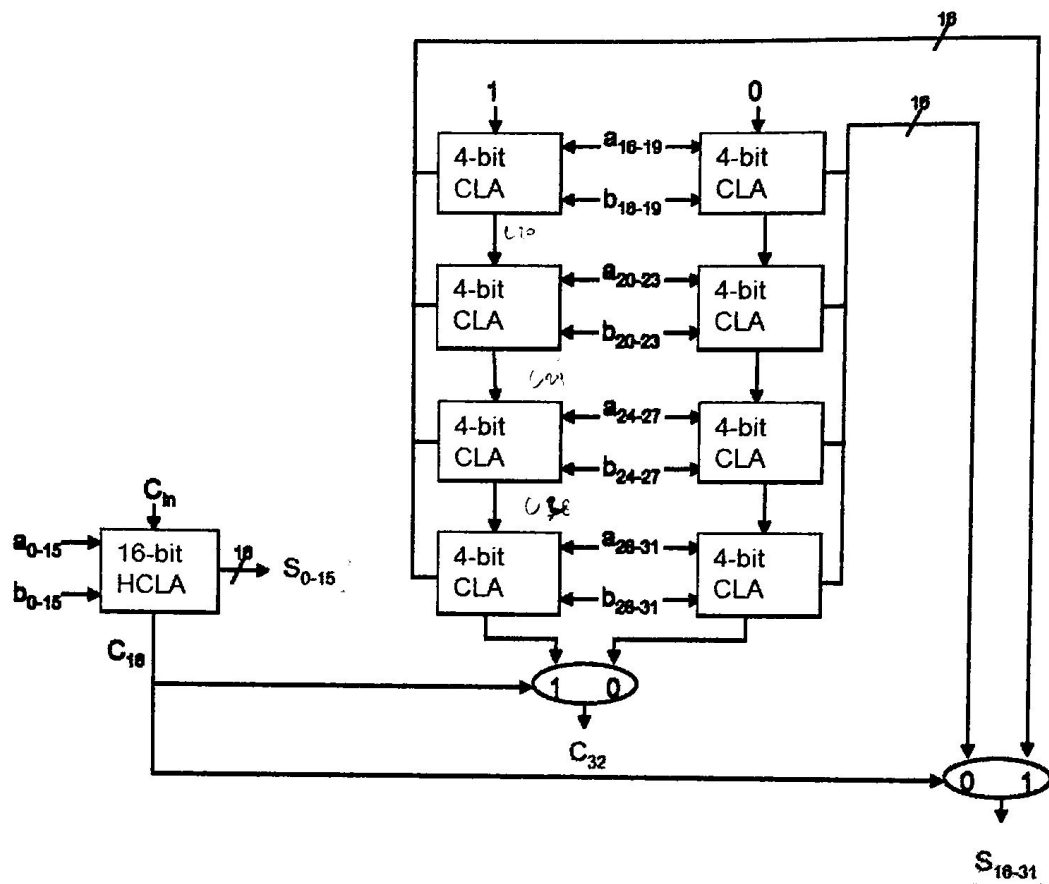
$\underbrace{54T + 7 = 61T}$
 $\underbrace{37T}$



$$44T + 7 = 51$$

$$C_{31} + 2 + 4$$

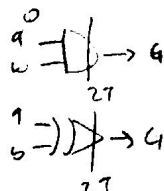
$$54 + 6 = 60$$



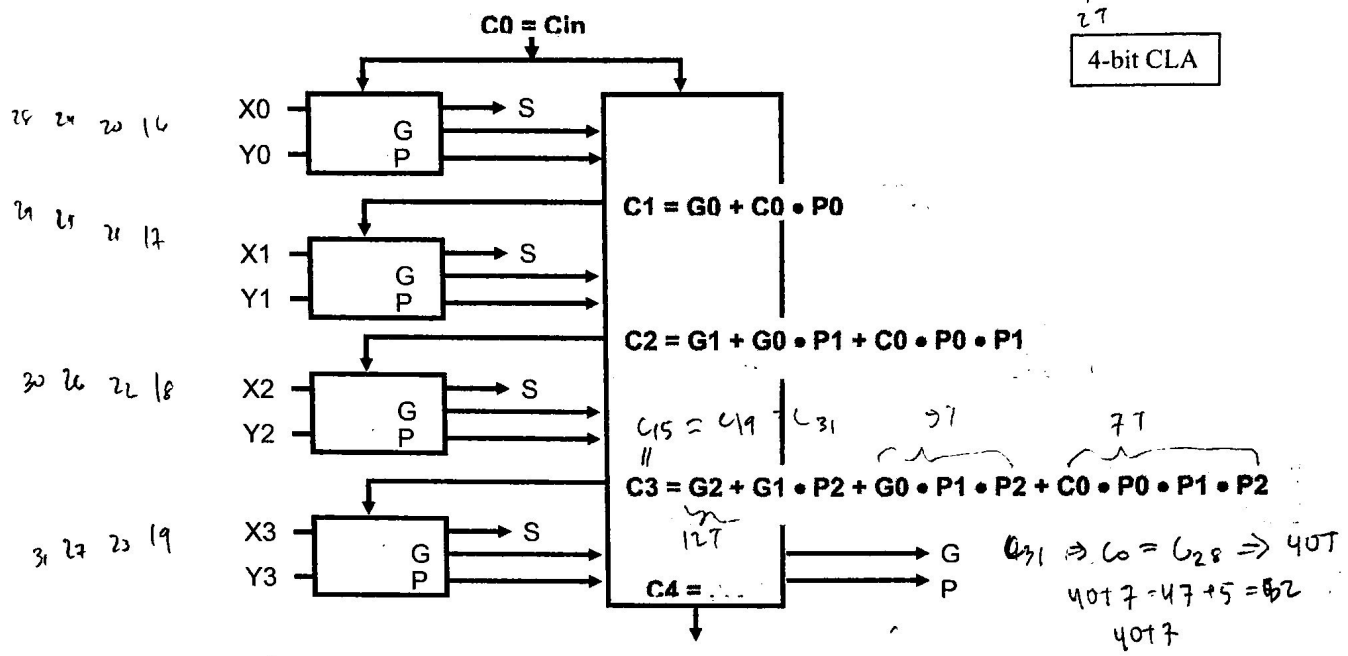
$$S_{15} = A \oplus B \oplus C_{15}$$

30T 30T 34

$G = A \text{ AND } B$
 $P = A \text{ XOR } B$



4-bit CLA

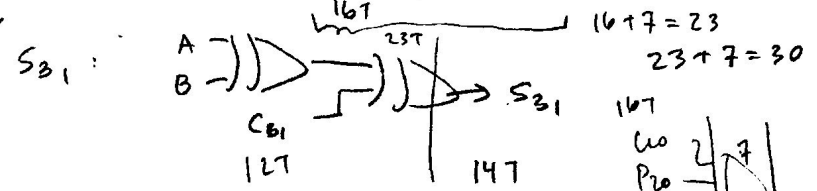


$C_6 = G_5 + G_4 P_5 + G_3 P_4 P_5 + G_2 P_3 P_4 P_5 + C_0 P_0 P_1 P_2 P_3 P_4 P_5$
 $9T + 7T = 16T$

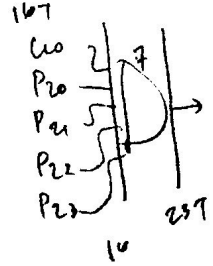
$C_{20} \rightarrow 30 \quad 30 + 5 = 35 + 5 = 40$

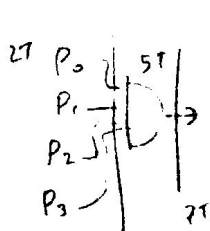
$C_{28} \rightarrow 40T \quad C_{31} \rightarrow G_3$
 $S_{19} = A \oplus B$

$C_{24} = G_{23} + G_{22} P_{23} + G_{21} P_{22} P_{23} + G_{20} P_{22} P_{23} P_{21} + C_{20} P_{20} P_{21} P_{22} P_{23}$
 $23T + 7T = 30T$
 $23 + 7 = 30$



$C_{15} = G_{14} + G_{13} P_{14} + G_{12} P_{13} P_{14} + C_{12} P_{12} P_{13} P_{14}$
 $25 + 5T = 30T$

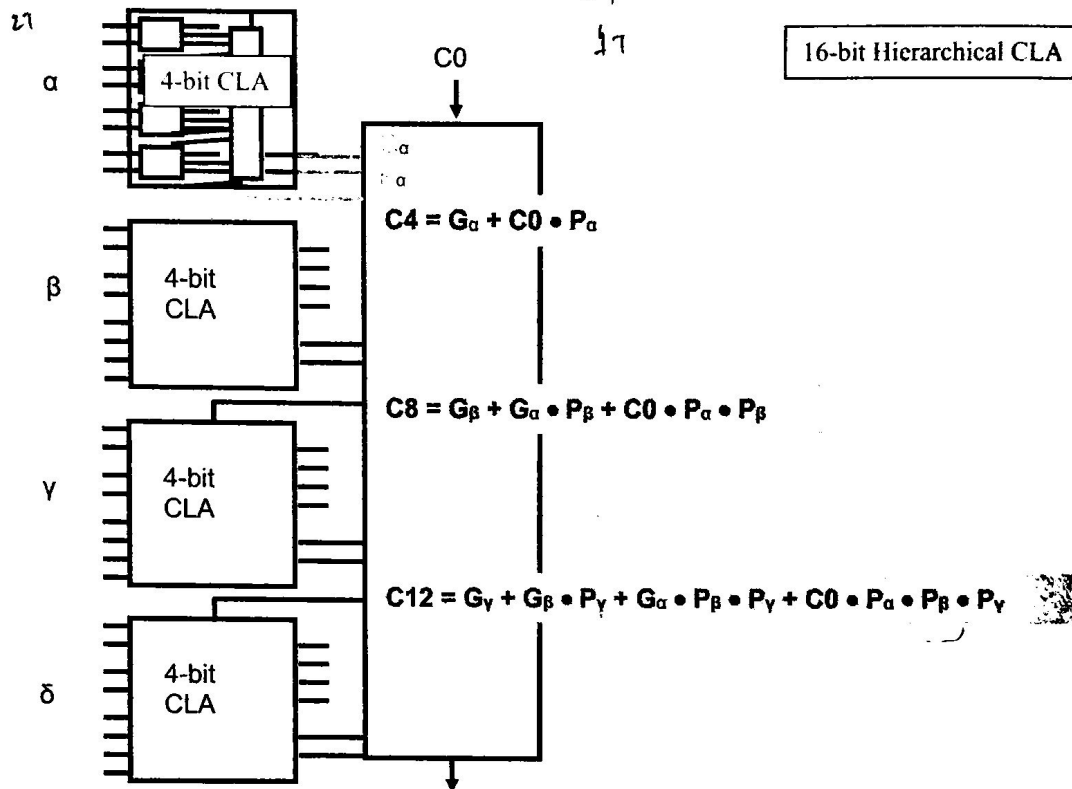




$$G_{\alpha} = G_3 + G_2 P_3 + G_1 P_2 P_3 + \underbrace{G_0 P_1 P_2 P_3}_{7T}$$

$$P_{\alpha} = P_0 P_1 P_2 P_3$$

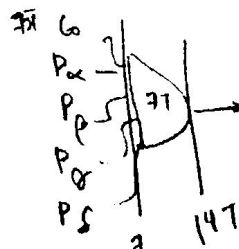
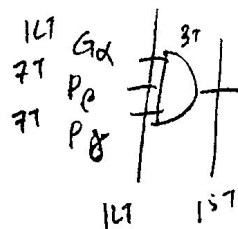
16-bit Hierarchical CLA



C16 = ...

$$C_{12} = G_{\gamma} + G_{\beta} P_{\gamma} + G_{\alpha} P_{\beta} P_{\gamma} + C_0 P_{\alpha} P_{\beta} P_{\gamma}$$

$$15T + 5T = 20T$$



$$C_{16} = G_{\delta} + G_{\gamma} P_{\delta} + G_{\beta} P_{\gamma} P_{\delta} + \underbrace{G_{\alpha} P_{\beta} P_{\gamma} P_{\delta}}_{14T} + \underbrace{C_0 P_{\alpha} P_{\beta} P_{\gamma} P_{\delta}}_{14T}$$

$$17T + 7T = 24T$$

